Exhibit J

Deep Space Telecommunications Systems Engineering

Joseph H. Yuen, Editor
Jet Propulsion Laboratory
California Institute of Technology

[redacted]

Deep Space Telecommunications Systems Engineering
(JPL Publication 82-76)

Library of Congress Catalog Card Number 82-084114

This book was prepared by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

July 1982

symbols is $K = N - d + 1$ and any combination of $(d - 1)/2 = (N - K)/2$ errors can be corrected. If we represent each letter in a codeword by J binary digits, then we can obtain a binary code with KJ information bits and block length NJ bits. Any noise sequence that alters at most $(N - K)/2$ of these J length sequences can be corrected, and thus the code has a burst correcting capability of $J[(N - K)/2 - 1] + 1$, along with the capability of correcting many combinations of multiple shorter bursts. Therefore Reed-Solomon codes are very appropriate on burst noisy channels such as a channel consisting of a convolutional encoder–AWGN channel–Viterbi decoder. Reed-Solomon codes will be discussed further in Section 5.4.4.

5.4.3 Convolutional Codes

A constraint length K, code rate $r = b/n$ (bits/symbol) convolutional encoder is a linear finite-state machine consisting of a bK-stage shift register and n linear algebraic function generators (Fig. 5-20). The input data, which is usually binary, is shifted at a bit rate of $1/T_b$ along the register b bits at a time. The output symbol rate is equal to $1/T_s = (rT_b)^{-1}$. In comparison to block codes, convolutional codes encode the input data bits continuously rather than in blocks. The convolutional encoder implementation is simpler and thus less costly and more reliable for spacecraft operation than a block encoder. A (b, n) linear block code can be regarded as a special case of a convolutional code with $K = 1$.

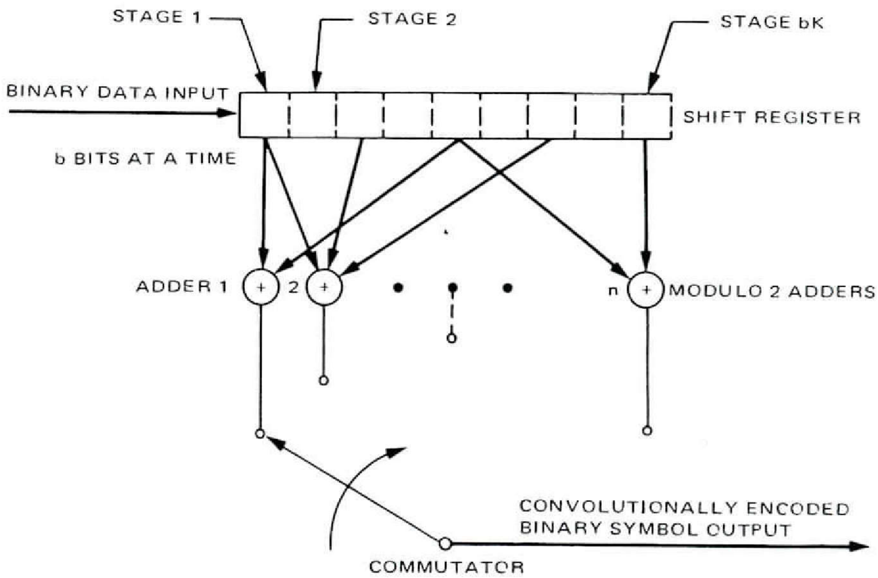
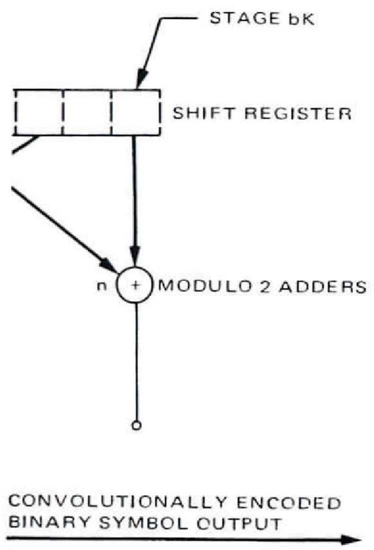


Fig. 5-20. Constraint length *K*, code rate *b/n* convolutional encoder

of $(d-1)/2 = (N-K)/2$ errors
a codeword by J binary digits,
ormation bits and block length
ɔst $(N-K)/2$ of these J length
has a burst correcting capabil-
ıbility of correcting many com-
Reed-Solomon codes are very
:hannel consisting of a convolu-
r. Reed-Solomon codes will be

'n (bits/symbol) convolutional
:ing of a bK-stage shift register
5-20). The input data, which is
$_b$ along the register b bits at a
$T_s = (rT_b)^{-1}$. In comparison to
: input data bits continuously
oder implementation is simpler
ıcecraft operation than a block
egarded as a special case of a



ꝛ

b/n convolutional encoder

The particular code structure depends on the manner in which the adders are connected to the shift register. These connections are denoted by a set of vectors

$$\mathbf{g}_i = (g_{i1}, g_{i2}, \cdots, g_{ibK}), \quad i = 1, 2, \cdots, n \tag{5.4-14}$$

where $g_{ij} = 1$ denotes a connection between the jth stage of the shift register and the ith adder, and $g_{ij} = 0$ denotes the absence of a connection. The complete set of $\mathbf{g}_i$ and the parameter b define the code. Figure 5-21 demonstrates the meaning of $\mathbf{g}_i$.

If the data bits are sent as part of the output, the code is termed "systematic." Otherwise, it is "nonsystematic." Thus, a systematic code is one which for some $1 \leqslant i \leqslant n$ and $0 \leqslant m \leqslant K - b$ (usually $i = 1$ and $m = 0$)

$$g_{i,m+j} = \begin{cases} 1; j = 1, 2, \cdots, b \\ 0; \text{otherwise} \end{cases} \tag{5.4-15}$$

Systematic codes have the advantage of the simple quick-look property. That is, since the data is present explicitly in the symbol stream, it can be examined without decoding.

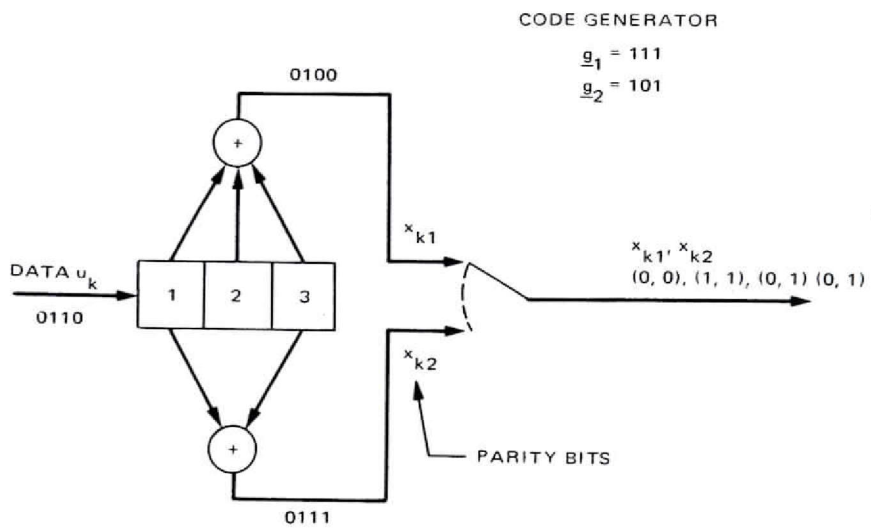


Fig. 5-21. Nonsystematic convolutional encoder with $K = 3$, $r = 1/2$; the code generator denotes the top positions

MSIFT00040238